NOAA/K RADAR DATA FROM THE RICO 2005 EXPERIMENT: DESCRIPTION AND VISUALIZATIONS

W.C. Campbell
R.J. Hill
D.C. Welsh

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Office of Oceanic and Atmospheric Research

NOAA Technical Memorandum OAR PSD-310

NOAA/K RADAR DATA FROM THE RICO 2005 EXPERIMENT: DESCRIPTION AND VISUALIZATIONS

W. Carroll Campbell
NOAA Earth Sciences Research Laboratory, Boulder, CO

Reginald J. Hill
CIRES, University of Colorado, Boulder, CO
NOAA Earth Sciences Research Laboratory, Boulder, CO

David C. Welsh
NOAA Earth Sciences Research Laboratory, Boulder, CO

Earth System Research Laboratory
Physical Sciences Division
Boulder, Colorado
June 2006

NOTICE:

Mention of a commercial company or product does not constitute an endorsement by NOAA/ESRL. Use of information from this publication concerning proprietary products or the tests of such products for publicity or advertising purposes is not authorized.

Contents

Figures

Appendix

NOAA/K Radar Data from the RICO 2005 Experiment: Description and Visualizations

W. Carroll Campbell, Reginald J. Hill, David C. Welsh

ABSTRACT. The NOAA/K radar was used to collect Ka-band radar data aboard ship during the RICO experiment. Ship's motion data were also recorded and later used to correct radial velocities and provide position information for each radar datum. This document describes the corrected radar data. In addition, three programs were written to produce files that would provide visualizations of this corrected data. These programs are described, and samples of the visualizations are given.

1.   INTRODUCTION

NOAA/K radar data were collected as part of the Rain In Cumulus over the Ocean (RICO) experiment (Rain In Cumulus over the Ocean, 2006) during the period 2005/01/09 – 2005/01/24. Data were collected for all days in this period except 01/15. The ship's position and motion data were recorded from the ship's Position and Orientation System for Marine Vessels (POS MV).

The NOAA/K radar (Martner et al., 2002) was designed for ground-fixed operation but was used aboard a ship for this experiment. Accordingly, many of the coordinate data are based on the radar's local frame of reference and not corrected for ship-board motion. However, the data have been reprocessed to include ship's motion data as provided by the POS MV system. The following description makes clear which parameters have been motion-corrected and which have not.

Typically, the radar acquires data by making a series of sweeps. In a sweep, one axis of the radar, either azimuth or elevation, is held fixed while the other axis is scanned. Then the fixed axis is stepped, and the sweep is repeated. This is repeated several times and defines a volume. A sweep becomes one file on disk.

The radar acquires data along its beam (also known as a ray) in regularly spaced range cells (also known as range gates). Since this radar's beam has a circular cross section, the range cells are in the shape of truncated cones stacked end-to-end along the beam.

This radar uses a pulse-pair pulsing scheme. A pair of closely spaced pulses is transmitted, and then, after a longer time, another pair of pulses is transmitted. In this experiment, the time between the pulse pairs was 1 ms, and the time between the pulses within the pair was 200 µs. Radial velocities were calculated from the phase difference between the two pulses within the pair. The radar processes data in groups of pulses called a beam. In this experiment, the radar operated with 256 pulses (128 pairs) in a beam; therefore, a beam was 128 ms long. Thus, there were roughly eight beams (rays) per second. More on the radar data processing system can be found in Gibson et al. (2004).

In RICO, the scans were all RHI (Range Height Indicator), which means that the azimuth was held fixed while the antenna scanned in elevation. Then, normally, the antenna would step

in azimuth and repeat the elevation sweep, except here the antenna step size was virtually zero, so it did not move in azimuth. Six elevation sweeps were performed; this defined the "volume." The time used for a sweep was 10 s, so a volume scan took one minute.

The data from the POS MV are described by Corcoran and Pronk (2003). The phase center of the NOAA/K radar antenna was surveyed and those position data were entered into the POS MV program such that the POS MV data for latitude, longitude, altitude, and velocity components in POS MV data Group 1 apply to the position of the phase center of the radar. Those POS MV data were used to remove the ship's motion from the radar radial velocity measurement, and to determine the Earth's reference-frame components of the unit vector in the direction of the radar beam, the elevation angle from the horizon, and the latitude, longitude, and altitude of each radar datum. Details of that calculation and definition of variables are given by Hill (2005).

The calculated variables are written to the Network Common Data Format (netCDF) file in the convention that altitude is positive upward and that (Eastward, Northward, Upward) is the right-handed coordinate system. On the other hand, the POS MV data written to the netCDF file are in the coordinate system convention of the POS MV. The POS MV data convention for altitude is that altitude is in meters and increases upward from the Global Positioning System (GPS) geoid. The GPS geoid is about 40 m above the sea surface in the RICO study area. Therefore, the ship's altitude varies from about -35 to -45 meters. The POS MV data use (Northward, Eastward, Downward) as the right-handed coordinate system, and a right-handed coordinate system fixed to the ship with coordinates (forward, starboard, keelward). The POS MV data for angular rates are right-handed rotations about that ship's axes. The roll, pitch, and heading from POS MV data are the time integrals of those angular rates and constitute the Euler angles for rotation of the ship's POS MV coordinate system to coincide with the POS MV Earth-frame coordinate system (Northward, Eastward, Downward). In the POS MV convention, vector components are positive in the downward direction, which is opposite to the POS MV convention for altitude as stated above. See Hill (2005) for details.

2.   DESCRIPTION OF RADAR DATA FILES

Radar data are being provided in the netCDF self-describing format. For details on this format, refer to http://www.unidata.ucar.edu/software/netcdf/. Appendix A contains a netCDF dump of the header file.

2.1 Global netCDF Attributes

These netCDF attributes apply to the whole file and are described below. The values used for example are from the first data set taken. The meaning of most of these attributes is obvious; clarifying comments have been added where appropriate. Quotes indicate a text string, and an "s" suffix on a number indicates that this number is a "short" (16-bit) integer.

:Project_Name = "RICO-05" ;

:Date = "2005/01/09" ;

:Site_Name = "Barbuda" ;

:Radar_Name = "NOAA/K" ;

:Radar_Type = "GROUND" ;

:Operator_Name = "BBartram" ;

:Scan_Mode = "s   " ;
The name that the operator gave this scan was "s."

:Mode_Number = 3s ;
The "3" indicates that this was a Range Height Indicator (RHI) scan. Azimuth was held fixed while the antenna was scanned in elevation.

:P3_mode = 170s ;
This indicates the type of data acquisition and processing done. Mode 170 indicates that both co-polarized and cross-polarized radar data were acquired simultaneously by the radar and processed using the pulse-pair processing algorithm. Cross-polarized data were not considered meaningful in this experiment and so do not appear in these data files.

:Tape = 134s ;
This is the tape number and is not meaningful since all data were recorded to disk.

:Volume_Number = 1s ;
This is a sequential number indicating the volume. Volume numbers increased sequentially throughout the experiment and ranged from 1 to 6303.

:Sweep_Number = 1s ;
This is a sequential number indicating the sweep number within the volume.

:First_Record = "2005/01/09 10:03:52" ;
Time that the first data record in the file was recorded.

:Time_Zone = "ast" ;
Atlantic Standard Time

:Time_Zone_Offset = -4 ;
Time zone offset in hours from GMT.

:Data_Type = "Meteorological Fields" ;

:Radar_Calibration_File = "Cal_Curve.dat" ;
This is the name of the radar calibration file that was used to process the data. If the entry is "none," then the receiver gain from the header was used to process the file. Calibration affects power and reflectivity values but not correlation or velocity.

2.2 Dimensions

Dimensions used for dimensioned variables in netCDF must be declared. Dimensions used here are "Time," which is an unlimited dimension, and "maxCells," which is 256 for the 256 range gates. The dimension "threshold" is used only for the co- and cross-polarized correlation thresholds. Dimension "vector" is used only for the Unit Vector (described below).

2.3 Variables

Variables used here are of type short, float, or double. Shorts are 16-bit signed integers, and a scale_factor attribute is usually used with them to convert them to the desired units. In particular, 0.0078125 or 1/128 is commonly used to give a range of about ±256 and a resolution of about 0.008. A float type is a 32-bit IEEE floating-point format variable. A double is a 64-bit double-precision IEEE floating-point variable.

A missing_value attribute is associated with each variable. If the value of a variable is not valid because of lack of signal or some sort of data dropout, missing_value is used for the variable's value.

2.3.1 Undimensioned Variables

double base_time ;
This is a double-precision, floating-point variable indicating the Unix time at the beginning of the file. Unix time is the time since 1970/01/01 at 00:00:00 GMT in seconds. Unix time is tied to UTC in the sense that leap seconds are added to Unix time at the same time that they are added to UTC.

short gates_number ;
This is the number of range cells used for each beam (or ray) in the file.

float Nyquist_Velocity ;
The Nyquist velocity is the maximum velocity in meters/second, either positive or negative, that the radar can directly measure without ambiguity. Positive velocities are receding, and negative velocities are approaching. Velocities that exceed the positive Nyquist velocity will show up at the negative Nyquist velocity.

float Range_to_First_Cell ;
Range in meters to the first range cell.

float Range_to_Last_Cell ;
Range in meters to the last range cell.

float Cell_Spacing ;
Spacing in meters between adjacent range cells along the beam.

float Fixed_Angle ;
The nonvarying angle during a scan. In RHI scans, as in RICO, this is the azimuth angle.

float Radar_Constant_Horizontal ;
The radar constant in dB for co-polarized data. The radar constant incorporates fixed characteristics of the radar, such as transmitted power, antenna gain, and antenna beamwidth, and is used, along with range, to calculate reflectivity from received power.

float Radar_Constant_Vertical ;
The radar constant in dB for cross-polarized data. This is not relevant for the data in RICO.

2.3.2 Variables Dimensioned by Threshold

float CorrelationThreshold(threshold) ;
Data are thresholded by a value of correlation. Data for which the correlation is below the threshold are not processed. There are two values, the first for the co-polarized channel threshold, and the second for the cross-polarized channel threshold. The second is not significant for RICO.

2.3.3 Variables Dimensioned by Time

The Time dimension might better be described as the beam (ray) number. It ranges from one to the maximum number of beams in the file, which is typically 82.

float time_offset(Time) ;
This is the offset in seconds from base_time.

float Latitude(Time) ;
This is the latitude in degrees north of the phase center of the radar antenna as obtained from the POS MV system.

float Longitude(Time) ;
This is the longitude in degrees east of the phase center of the radar antenna as obtained from the POS MV system.

float Altitude(Time) ;
This is the altitude in meters of the phase center of the antenna as obtained from the POS MV system. This is the altitude from the GPS geoid. Altitude increases upward.

float Elevation(Time) ;
This is the elevation in degrees above the ship's deck as determined from the radar's angle encoder. This elevation can range from about 0° to 160°.

float Azimuth(Time) ;
This is the azimuth in degrees from the ship's bow as determined from the radar's angle encoder. Ninety degrees means pointing off the ship's starboard side.

float CorrectedElevation(Time) ;
This is the elevation in degrees above the horizon corrected for the ship's motion. See Eq. 15 of Hill (2005). This elevation can range from negative values when the beam is below the starboard horizon to 0° when the beam is at the starboard horizon to 90° if the beam points to zenith.

float ImageElevation(Time) ;
This is for use in radar image plots. It varies from 0° when the beam is at the starboard horizon to 90° if the beam points to zenith and to 180° at the port-side horizon. It is negative when the beam is below the horizon.

float NorthVelocity(Time) ;
This is the northward velocity in meters/second of the phase center of the radar antenna as determined by the POS MV system.

float EastVelocity(Time) ;
This is the eastward velocity in meters/second of the phase center of the radar antenna as determined by the POS MV system.

float DownVelocity(Time) ;
This is the downward velocity in meters/second of the phase center of the radar antenna as determined by the POS MV system.

double VesselRoll(Time) ;
This is the roll of the vessel in degrees as determined by the POS MV system. See the Introduction and Sec. 2.2 of Hill (2005).

double VesselPitch(Time) ;
This is the pitch of the vessel in degrees as determined by the POS MV system. See the Introduction and Sec. 2.2 of Hill (2005).

double VesselHeading(Time) ;
This is the heading of the vessel in degrees as determined by the POS MV system. See the Introduction and Sec. 2.2 of Hill (2005).

float VesAngRateLong(Time) ;
This is the angular rate in degrees/second of the vessel about its forward axis as determined by the POS MV system. See the Introduction and Eq. 2 of Hill (2005).

float VesAngRateTrans(Time) ;
This is the angular rate in degrees/second of the vessel about its starboard axis as determined by the POS MV system. See the Introduction and Eq. 2 of Hill (2005).

float VesAngRateDown(Time) ;
This is the angular rate in degrees/second of the vessel about its keelward axis as determined by the POS MV system. See the Introduction and Eq. 2 of Hill (2005).

2.3.4 Variables Dimensioned by Time and MaxCells

short ve(Time, maxCells) ;
This is the radial velocity in meters/second uncorrected for ship's velocity. Positive velocities pertain to motion away from the radar. This value will always be between –Nyquist velocity and +Nyquist velocity.

short c0(Time, maxCells) ;
This is the correlation coefficient from the pulse-pair algorithm. Correlation values range from 0.0 to 1.0 with strong signals producing values approaching one. This value is used as a data quality indicator and indicates when other radar variables are valid. See Gibson et al. (2004).

short z0(Time, maxCells) ;
This is reflectivity in dBZ as calculated from the received power p0, range, and radar constant. This parameter is not corrected for atmospheric attenuation.

short p0(Time, maxCells) ;
This is the power at the antenna terminals measured in dBm (dB referenced to 1 milliwatt). This number comes from the measured power at the output of the receiver and is calculated from it by using either the receiver gain or the calibration curve. It is DC corrected. Power is used to calculate reflectivity and ranges from a low value of about -105 dBm (receiver noise floor) to a maximum of about -20 dBm (receiver saturation).

The following variables are corrected for ship's motion using the ship's POS MV data, not by means of the radar's GPS system.

short cve(Time, maxCells) ;
This is the radial velocity in meters/second corrected for the velocity at the phase center of the radar antenna.

float lat(Time, maxCells) ;
This is the latitude in degrees north of each range cell. See Eq. 16 of Hill (2005).

float lon(Time, maxCells) ;
This is the longitude in degrees east of each range cell. See Eq. 17 of Hill (2005).

float altr(Time, maxCells) ;
This is the altitude in meters from the GPS geoid for each range cell; altr increases upward. The GPS geoid in the RICO study area is about 40 meters above the sea surface. See Eq. 18 of Hill (2005).

float altm(Time, maxCells) ;
This is the altitude above the instantaneous sea level (i.e., above the ship's water line) in meters for each range cell; altm increases upward. The ship's water line was observed for the ship's trim at the RICO study area. Water line level can vary according to how much ballast water the ship has taken. See Eq. 20 of Hill (2005).

2.3.5 Variables Dimensioned by Time and Vector

double UnitVector(Time, vector) ;
This is the unit vector in the Earth's coordinate system pointing in the direction of each radar beam. See Eq. 12 of Hill (2005). The three components of UnitVector are (East, North, Up), unlike the POS MV convention of (North, East, Down).

3.   RADAR DATA VISUALIZATION PROGRAMS

3.1 Overview

Three different radar data visualization programs and one utility program are described here. The source listings and save files for these programs can be found on the RICO FTP site, which is currently at ftp://ftp.etl.noaa.gov/et6/archive/RICO/SEWARD_JOHNSON/radar/NOAA_K/. These programs are written in the Interactive Data Language (IDL) from ITT Visual Information Solutions (formerly Research Systems, Incorporated). Although it is necessary to have a license in order to alter and recompile the source files, a free download of the IDL Virtual Machine (IDL Virtual Machine Download, 2006) is available that can be used to run the save files. The IDL Virtual Machine is available for all commonly used operating systems.

After installation of the IDL Virtual Machine, programs stored as *.sav files can be run by dragging the file icon onto the IDL Virtual Machine icon or by opening the IDL Virtual Machine and reading the save file.

All three of the data visualization programs produce files that provide a look at the reflectivity and velocity fields, but in different ways. ScanPlotRelative and ScanPlotFixed both produce GIF files that are suitable for animation. ScanPlot3D produces *.isv files that can be opened with IDL or iPlotter (section 3.5) and that allow the user to interactively translate, scale, and rotate the images.

The ScanPlotRelative program (section 3.2) provides a 2D look at the velocity and reflectivity fields from a viewpoint orthogonal to the plane of the radar's scan. Because of the ship's motion, some geometric distortion in the view is inevitable because the scan's surface is not a plane.

ScanPlotFixed (section 3.3) also provides 2D GIF files but from a viewpoint that gives a 3D perspective. ScanPlotFixed also shows the ship's path and orientation.

The files from ScanPlot3D (section 3.4) provide the most detailed look at a particular scan with its user interactive features, but the images are not suitable for animation. iPlotter must be used if the IDL Virtual Machine is being used to look at the *.isv files produced by ScanPlot3D.

3.2 ScanPlotRelative

Figure 1 shows an example of a GIF file produced from the ScanPlotRelative program. When the program starts, the user is asked to select the files to process on a Graphical User Interface (GUI) menu. The user then navigates to the correct directory and highlights the desired files. Output files are written in the same directory and have the form of NOAA-K-*YYYYMMDD*.2Dr.*nnnn*.gif, where *YYYYMMDD* is the date and *nnnn* is a sequence number. For example, the file shown in Figure 1 is named NOAA-K-20050109.2Dr.0001.gif.
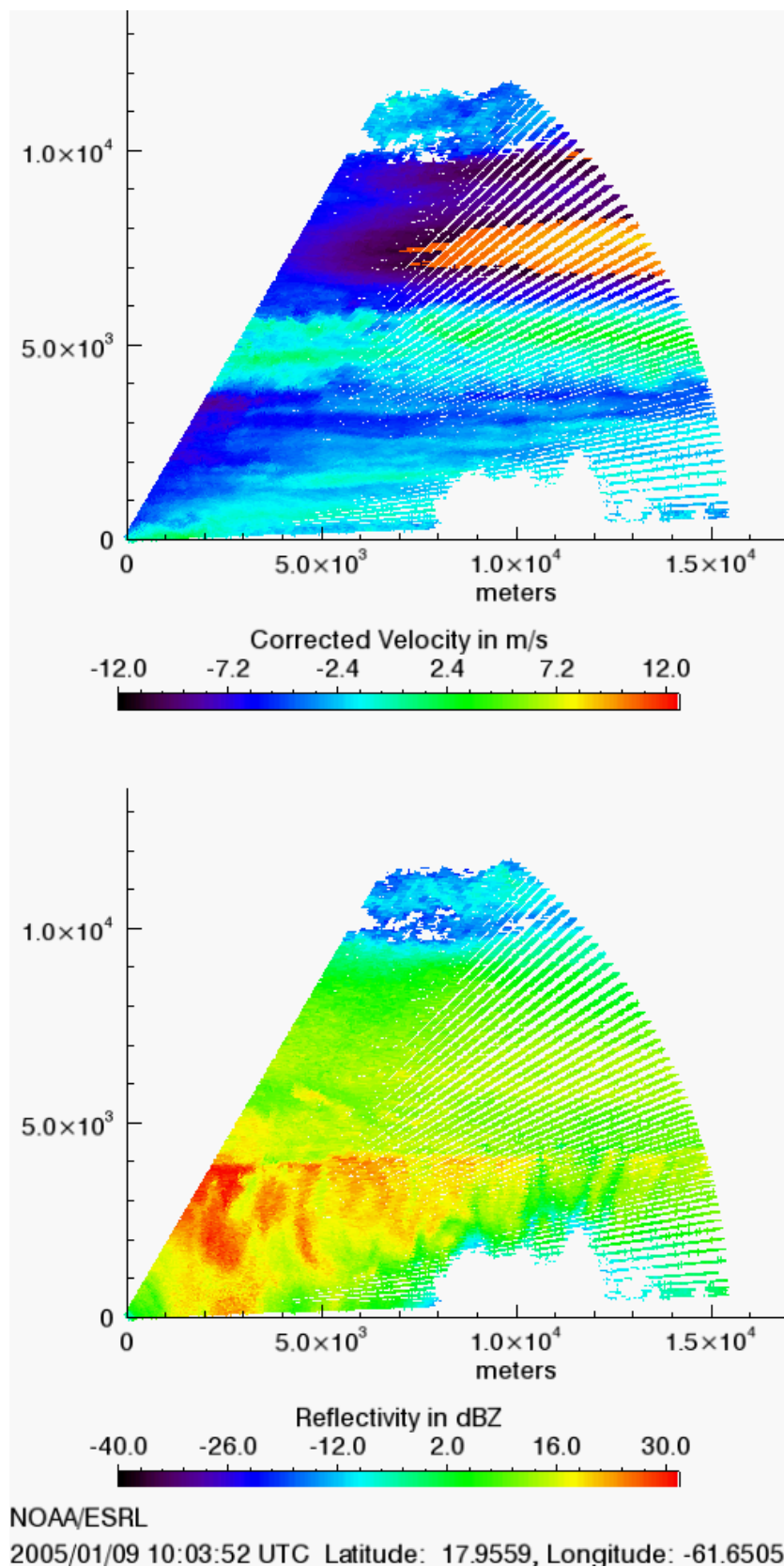
Figure 1. Sample of GIF file produced from ScanPlotRelative program.

3.3 ScanPlotFixed

Figure 2 shows an example of a GIF file created by the ScanPlotFixed program. The operator selects files as in the previous program, but now all the selected files are interrogated to determine the extremes of latitude, longitude, and altitude. These extremes are then used to determine the range of the plotting. This allows the ship's motion and orientation to be viewed in the plots.
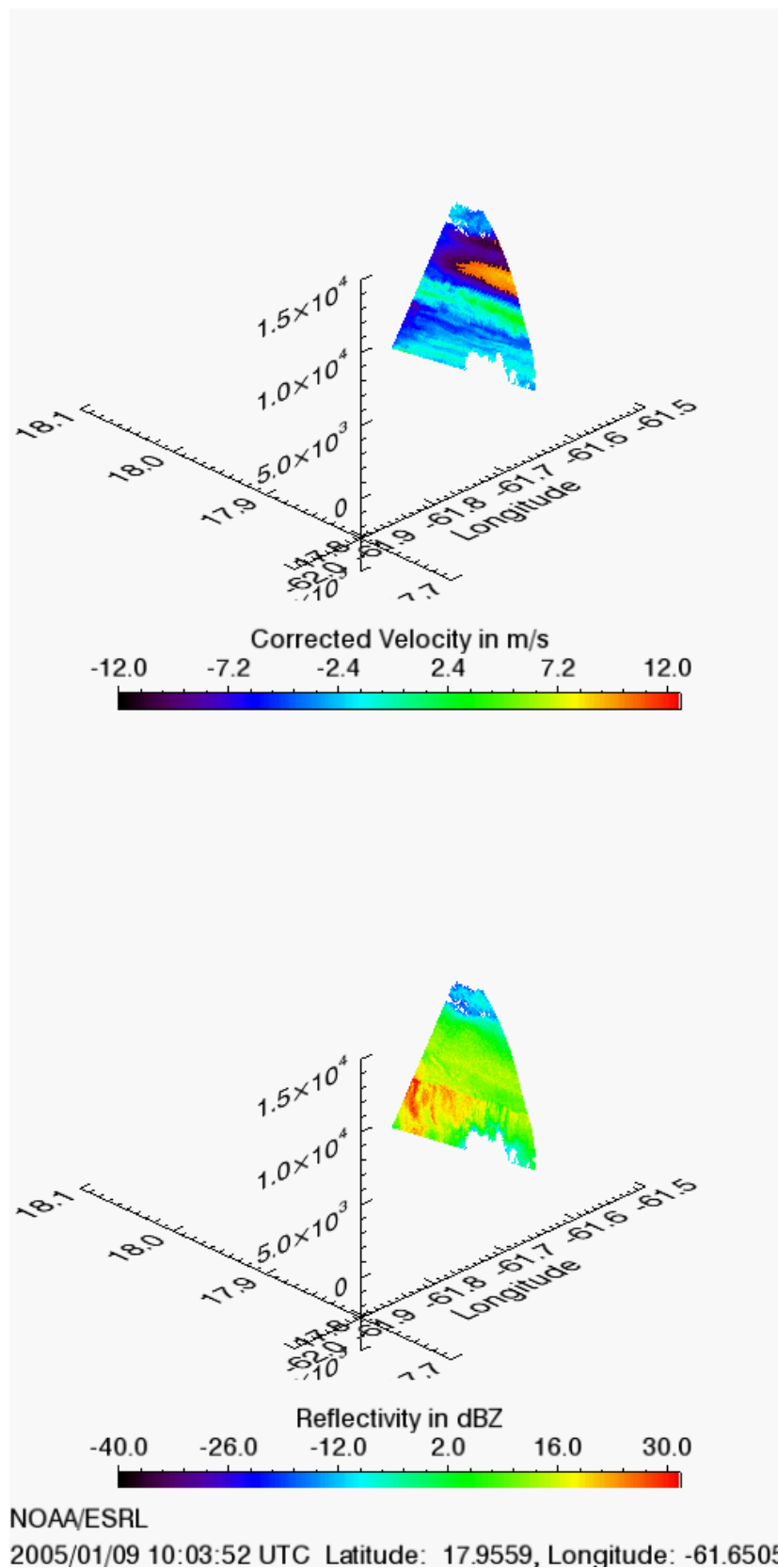
Figure 2. Sample of GIF file produced by the ScanPlotFixed program.

3.4 ScanPlot3D

Figure 3 shows the appearance of a file produced from ScanPlot3D when opened with IDL.
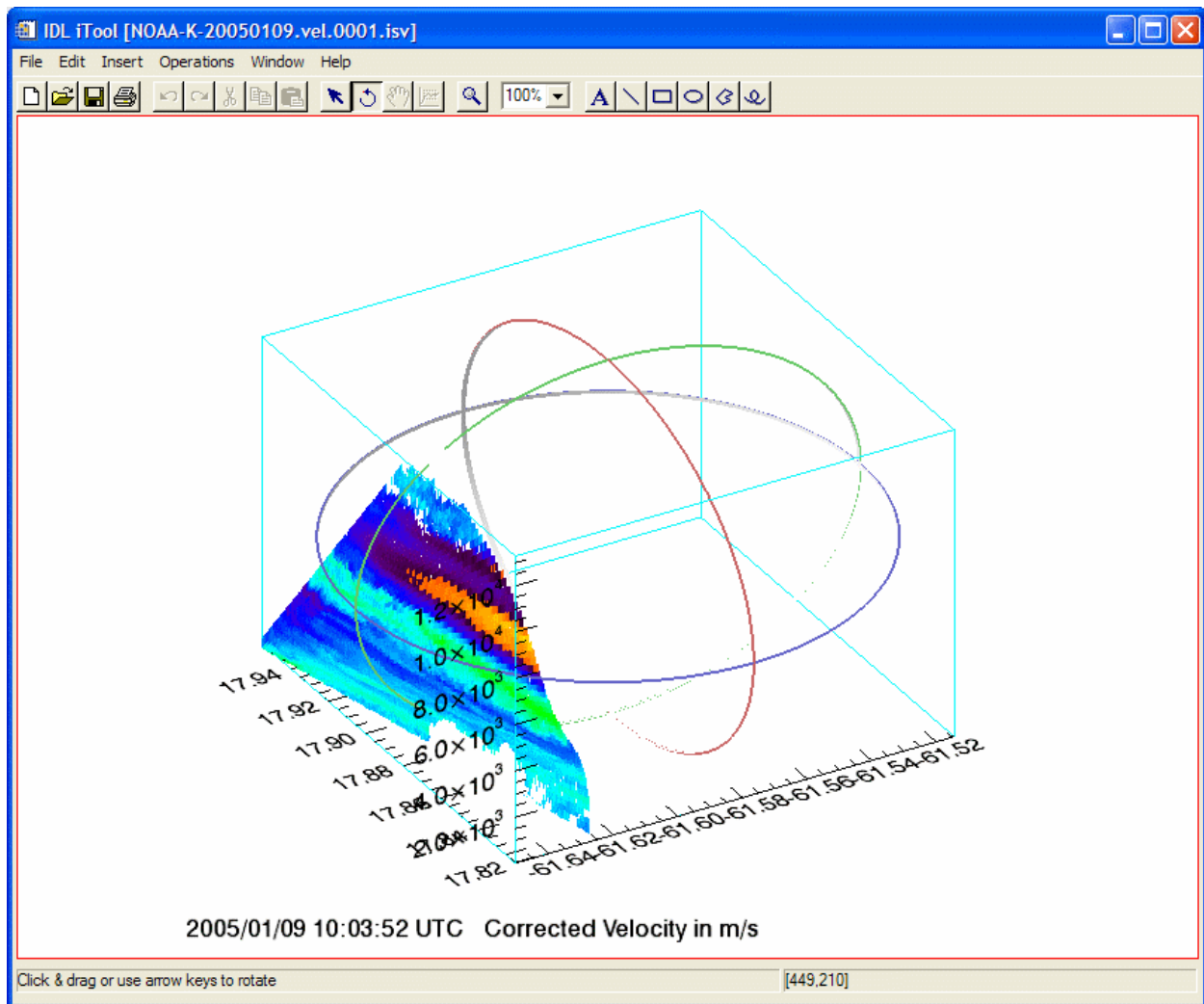

Figure 3. Sample of 3D visualization of file produced by the ScanPlot3D program.

In the visualization, the rings can be grabbed with the mouse and used to rotate the image. It is also possible to interactively translate and scale the image. For example, Figure 4 is a rotated view of Figure 3 that was produced by use of the mouse.
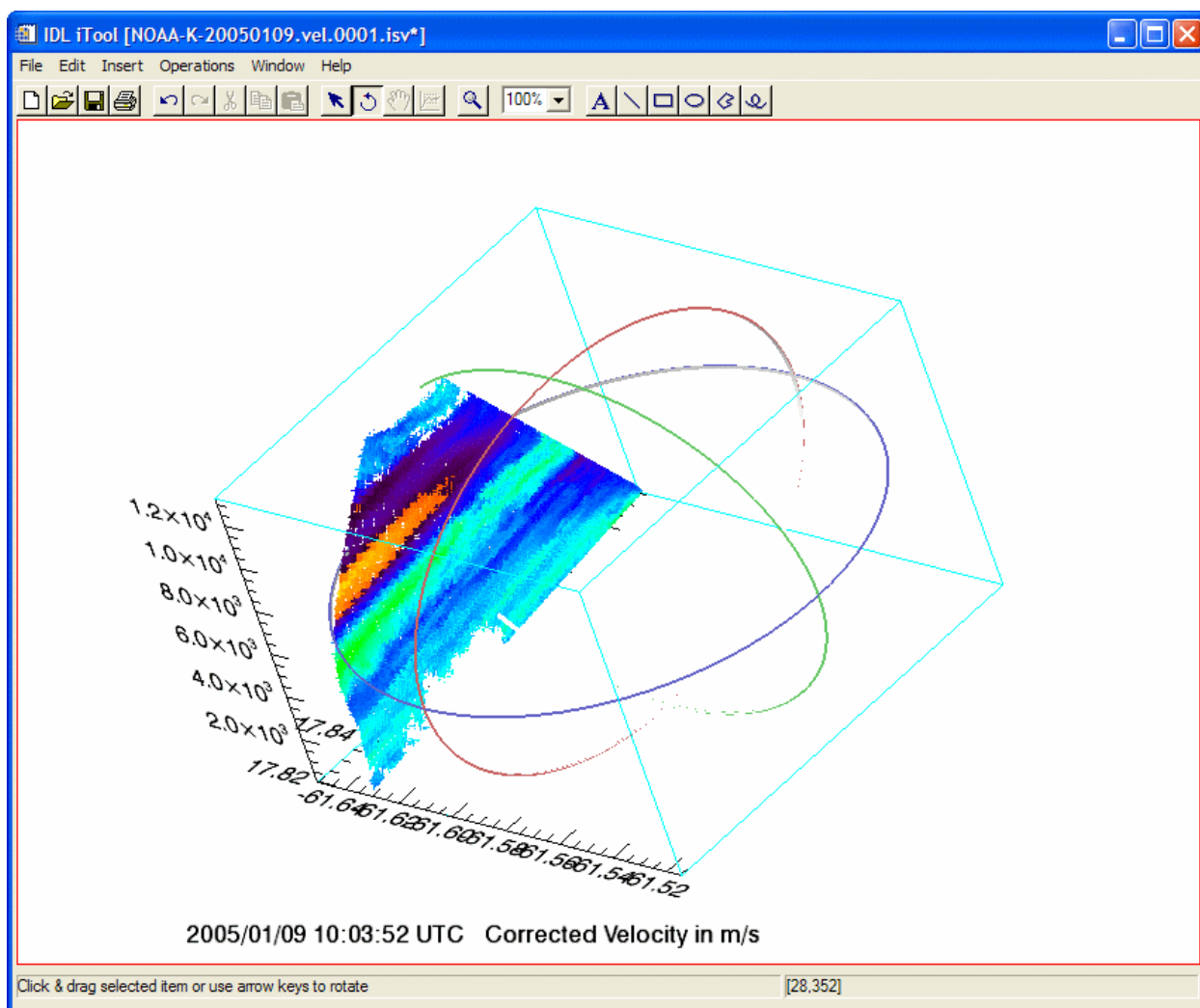
Figure 4. Rotated view of Fig. 3.

The color bars are produced in a window when ScanPlot3D runs. Figure 5 shows the color bars corresponding to Figure 3, Figure 4 and Figure 6.
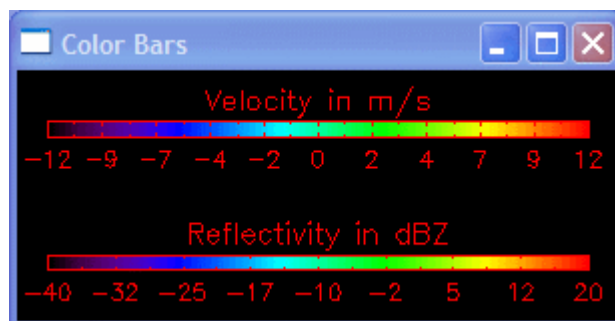
Figure 5. Color bars for 3D plots.

Figure 6 shows a 3D visualization of reflectivity. Both reflectivity and velocity fields are produced by ScanPlot3D.
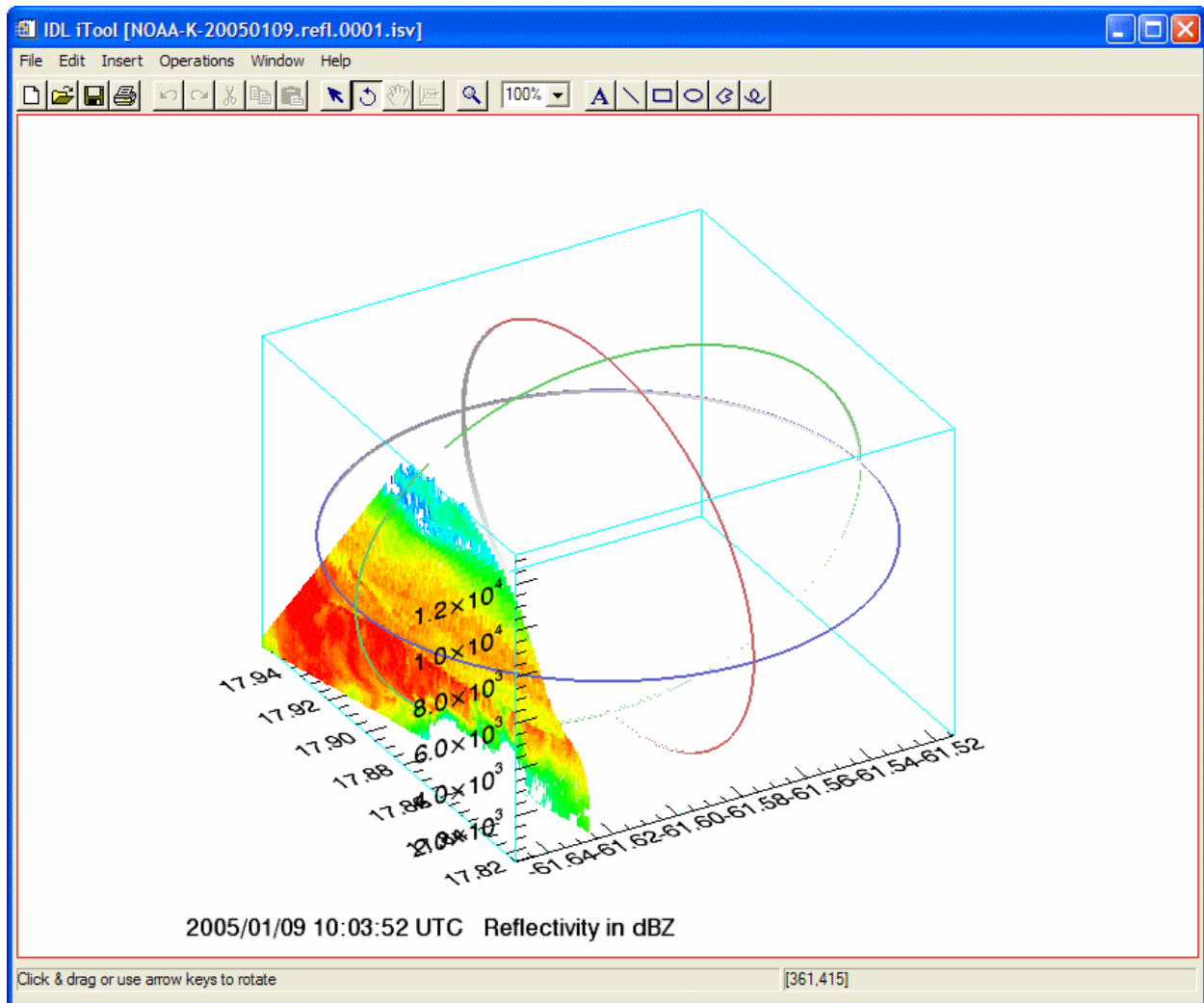
Figure 6. Sample 3D visualization of reflectivity field produced by the ScanPlot3D program. This is from the same data set shown in Figure 3 but with a different field. The color bars for this field are shown in Figure 5.

3.5 iPlotter

This short program opens an empty iPlot tool. Then, the facilities provided in this tool can be used to open and manipulate the *.isv files produced by ScanPlot3D. It is necessary to use this if the IDL Virtual Machine is being used. If a licensed copy of IDL is being used, it is only necessary to double-click on the *.isv file name to open the file.

4.   ACKNOWLEDGMENTS

5.   REFERENCES

Corcoran, R., and R. Pronk, 2003, POS MV Model 320 V30 Ethernet & SCSIICD, Applanix Corp.

Gibson, J. S., W. C. Campbell, and B. E. Martner, 2004, RADS: A Radar Acquisition and Display System for Research Radars, NOAA Technical Report OAR ETL-69. (Available at http://www.etl.noaa.gov/~bmartner/ under Radar Acquisition & Display System (RADS).)

Hill, R. J., 2005, Motion Compensation for Shipborne Radars and Lidars, NOAA Technical Memorandum OAR PSD-309. (Available at ftp://ftp.etl.noaa.gov/et6/archive/RICO/SEWARD_JOHNSON/radar/NOAA_K/RICOMotionComp3-15-06.pdf.)

IDL Virtual Machine Download. (2006). Retrieved 2006/05/23 from ITT Visual Information Solutions Web site: http://www.ittvis.com/download/download.asp?urlProductcode=13.

Martner, B. E., B. W. Bartram, J. S. Gibson, W. C. Campbell, R. F. Reinking, and S. Y. Matrosov, 2002: An overview of NOAA/ETL's scanning Ka-band cloud radar. Preprints, *16th Conf. on Hydrology,* Orlando, FL, Amer. Meteor. Soc., 21–23.

Rain In Cumulus over the Ocean. (2006). Retrieved 2006/05/23 from University Corporation for Atmospheric Research Web site: http://www.joss.ucar.edu/rico/.

Header dump of netCDF header file

```
netcdf 01.09.05.18.10.25.vol.431.001.met.rc {
dimensions:
        Time = UNLIMITED ; // (20 currently)
        maxCells = 256 ;
        threshold = 2 ;
        vector = 3 ;
variables:
        double base_time ;
                base_time:long_name = "UNIX Date/Time value for first record" ;
                base_time:units = "seconds since 1970-01-01 00:00 UTC" ;
        short gates_number ;
                gates_number:long_name = "Number of Range Gates in the Volume" ;
                gates_number:units = "count" ;
        float Nyquist_Velocity ;
                Nyquist_Velocity:long_name = "Effective unambiguous velocity" ;
                Nyquist_Velocity:units = "meters/second" ;
        float Range_to_First_Cell ;
                Range_to_First_Cell:long_name = "Range to the First Cell" ;
                Range_to_First_Cell:units = "meters" ;
        float Range_to_Last_Cell ;
                Range_to_Last_Cell:long_name = "Range to the Last Cell" ;
                Range_to_Last_Cell:units = "meters" ;
        float Cell_Spacing ;
                Cell_Spacing:long_name = "Distance between cells" ;
                Cell_Spacing:units = "meters" ;
        float Fixed_Angle ;
                Fixed_Angle:long_name = "Fixed angle for this scan" ;
                Fixed_Angle:units = "degrees" ;
        float Radar_Constant_Horizontal ;
                Radar_Constant_Horizontal:long_name = "Horizontal radar constant" ;
                Radar_Constant_Horizontal:units = "dB" ;
        float Radar_Constant_Vertical ;
                Radar_Constant_Vertical:long_name = "Vertical radar constant" ;
                Radar_Constant_Vertical:units = "dB" ;
        float CorrelationThreshold(threshold) ;
                CorrelationThreshold:long_name = "Correlation Threshold for Main and Cross
Channels" ;
                CorrelationThreshold:units = "none" ;
        float time_offset(Time) ;
                time_offset:long_name = "Time_offset of the current record from the base_time" ;
                time_offset:units = "seconds" ;
                time_offset:C_format = "%9.3f" ;
        float Latitude(Time) ;
                Latitude:long_name = "Latitude of the phase center of the antenna" ;
                Latitude:units = "degrees_north" ;
        float Longitude(Time) ;
                Longitude:long_name = "Longitude of the phase center of the antenna" ;
                Longitude:units = "degrees_east" ;
        float Altitude(Time) ;
                Altitude:long_name = "Altitude of the phase center of the antenna from GPS geoid"
;
                Altitude:units = "meters" ;
        float Elevation(Time) ;
                Elevation:long_name = "Ship relative elevation of the ray" ;
                Elevation:units = "degrees" ;
        float Azimuth(Time) ;
                Azimuth:long_name = "Ship relative azimuth of the ray" ;
                Azimuth:units = "degrees" ;
        float CorrectedElevation(Time) ;
                CorrectedElevation:long_name = "Corrected Earth relative elevation of the ray" ;
                CorrectedElevation:units = "degrees" ;
        float ImageElevation(Time) ;
                ImageElevation:long_name = "Corrected elevation, 0 at the starboard horizon to 180
at port-side horizon" ;
                ImageElevation:units = "degrees" ;
        float NorthVelocity(Time) ;
                NorthVelocity:long_name = "POS-MV north velocity of the phase center of the
antenna" ;
                NorthVelocity:units = "m/s" ;
```

```
        float EastVelocity(Time) ;
                EastVelocity:long_name = "POS-MV east velocity of the phase center of the antenna"
;
                EastVelocity:units = "m/s" ;
        float DownVelocity(Time) ;
                DownVelocity:long_name = "POS-MV down velocity of the phase center of the antenna"
;
        double VesselRoll(Time) ;
                VesselRoll:long_name = "POS-MV vessel roll" ;
                VesselRoll:units = "degrees" ;
        double VesselPitch(Time) ;
                VesselPitch:long_name = "POS-MV vessel pitch" ;
                VesselPitch:units = "degrees" ;
        double VesselHeading(Time) ;
                VesselHeading:long_name = "POS-MV vessel heading" ;
                VesselHeading:units = "degrees" ;
        float VesAngRateLong(Time) ;
                VesAngRateLong:long_name = "POS-MV vessel angular rate about longitudinal axis" ;
                VesAngRateLong:units = "degrees/s" ;
        float VesAngRateTrans(Time) ;
                VesAngRateTrans:long_name = "POS-MV vessel angular rate about transverse axis" ;
                VesAngRateTrans:units = "degrees/s" ;
        float VesAngRateDown(Time) ;
                VesAngRateDown:long_name = "POS-MV vessel angular rate about down axis" ;
                VesAngRateDown:units = "degrees/s" ;
        short ve(Time, maxCells) ;
                ve:long_name = "VE(VShD) - Doppler velocity from main channel, DC-corrected" ;
                ve:units = "meters/second" ;
                ve:missing_value = -32768s ;
                ve:scale_factor = 0.0078125f ;
        short c0(Time, maxCells) ;
                c0:long_name = "C0(CShD) - correlation, main channel" ;
                c0:units = "none" ;
                c0:missing_value = -32768s ;
                c0:scale_factor = 0.0078125f ;
        short z0(Time, maxCells) ;
                z0:long_name = "Z0(ZShD) - reflectivity, main channel, DC-corrected" ;
                z0:units = "dBZ" ;
                z0:missing_value = -32768s ;
                z0:scale_factor = 0.0078125f ;
                z0:derived_from = "R(0)" ;
        short p0(Time, maxCells) ;
                p0:long_name = "P0(PShD) - power, main channel, DC-corrected" ;
                p0:units = "dBm" ;
                p0:missing_value = -32768s ;
                p0:scale_factor = 0.0078125f ;
                p0:derived_from = "R(0)" ;
        float cve(Time, maxCells) ;
                cve:long_name = "VE(VShD) Corrected for ship motion - Doppler velocity from main
channel, DC-corrected" ;
                cve:units = "meters/second" ;
                cve:missing_value = 3.e+38f ;
        float lat(Time, maxCells) ;
                lat:long_name = "Latitude of cell" ;
                lat:units = "degrees" ;
                lat:missing_value = 3.e+38f ;
        float lon(Time, maxCells) ;
                lon:long_name = "Longitude of cell" ;
                lon:units = "degrees" ;
                lon:missing_value = 3.e+38f ;
        float altr(Time, maxCells) ;
                altr:long_name = "Altitude of cell from the GPS geoid" ;
                altr:units = "meters" ;
                altr:missing_value = 3.e+38f ;
        float altm(Time, maxCells) ;
                altm:long_name = "Altitude of cell above the instantaneous sea level" ;
                altm:units = "meters" ;
                altm:missing_value = 3.e+38f ;
        double UnitVector(Time, vector) ;
                UnitVector:long_name = "Unit vector in Earth coordinate system: East, North, Up" ;
                UnitVector:units = "n/a" ;
```

```
// global attributes:
                :Project_Name = "RICO-05" ;
                :Date = "2005/01/09" ;
                :Site_Name = "Barbuda" ;
                :Radar_Name = "NOAA/K" ;
                :Radar_Type = "GROUND" ;
                :Operator_Name = "BBartram" ;
                :Scan_Mode = "s        " ;
                :Mode_Number = 3s ;
                :P3_mode = 170s ;
                :Tape = 134s ;
                :Volume_Number = 1s ;
                :Sweep_Number = 1s ;
                :First_Record = "2005/01/09 18:10:24" ;
                :Time_Zone = "ast" ;
                :Time_Zone_Offset = -4 ;
                :Data_Type = "Meteorological Fields" ;
                :Radar_Calibration_File = "Cal_Curve.dat" ;
                :Radar_Data_Report =
"ftp://ftp.etl.noaa.gov/et6/archive/RICO/SEWARD_JOHNSON/radar/NOAA-K/" ;
}
```